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PROPAGATION OF INTRASUBBAND PLASMONS IN WEAKLY DISORDERED ARRAY OF QUANTUM WIRES

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ABSTRACT

The paper deals with the theoretical investigation of intrasubband plasmons in weakly disordered array of quantum wires (QWs), consisting of finite number of QWs. The array of QWs is characterized by the fact that the density of electrons of one "defect" QW is different from that of other QWs. It is shown that the amount of plasmon modes in weakly disordered array of QWs is equal to the number of QWs in array. The existence of a local plasmon mode, whose properties differ from those of usual modes, is found. We point out that the local plasmon mode spectrum is slightly sensitive to the position of "defect" QW in array. At the same time the spectrum of usual plasmon modes is shown to be very sensitive to the position of "defect" QW.

INTRODUCTION

Quasi one-dimensional electron systems (1DES) or quantum wires (QWs) are artificial structures in which the motion of charge carriers is confined in two transverse directions but is essentially free (in the effective mass sense) in the longitudinal direction. Collective charge-density excitations, or plasmons in QWs, are the objects of great physical interest due to some unusual dispersion properties. Firstly, the plasmon spectrum depends strongly on the width of QW [1]. Secondly, 1D plasmons are free from the Landau damping [2] in the whole range of wavevectors.

From the point of view of practical application so-called weakly disordered arrays of low-dimensional systems, containing some defect, are the objects of interest. Recently the plasmons in weakly disordered superlattice, formed of finite number of equally spaced two-dimensional electron systems (2DES), were theoretically investigated [3].

This paper deals with theoretical investigation of plasmons in finite weakly disordered array of QWs consisting of a finite number M of QW located in the planes $z=ld$ ($l=0, \dots, M-1$ is the number of a QW, d is the distance between adjacent QWs). We suppose that all QWs possess equal 1D density of electrons N except one "defect" QW whose density of electrons is equal to N_d. So, the density of electrons in l-th QW can be expressed as $N_l=(N_d-N)\delta_{pl}+N$. Here p is the number of "defect" QW arranged at the plane $z=pd$, δ_{pl} is the Cronecker delta. QWs are placed into a uniform dielectric medium with dielectric constant ε. We consider the movement of electrons to be free in the x-direction and is considerably confined in the directions along the y and z-axes. At the same time we suppose that the width of all QWs is equal to a in the y-direction and is equal to zero in the z-direction.

DISPERSION RELATION AND NUMERICAL RESULTS

To obtain the collective excitation spectrum we start with a standard linear-response theory in a random phase approximation. We also take into account only the lowest

subband in each QW. The dispersion relation for intrasubband plasmons can be represented in the final form as

$$\det\left|\delta_{l,l'} - \Pi^{l'} U_{l,l'}\right| = 0, \tag{1}$$

where

$$U_{l,l'} = \frac{8e^2}{\varepsilon a^2} \int_{-a/2}^{a/2} dy' \int_{-a/2}^{a/2} dy\, K_0\left(q_x \sqrt{(y-y')^2 + (l-l')^2 d^2}\right) \cos^2\left(\frac{\pi y}{a}\right) \cos^2\left(\frac{\pi y'}{a}\right), \tag{2}$$

$K_0(x)$ is the zeroth-order modified Bessel function of the second kind, $\Pi^{l'}$ is the noninteracting 1D polarizability ("bare bubble") function, which at zero temperature and in the long-wavelength limit (where $q_x \to 0$) can be written as $\Pi^l = \frac{N_l}{m^*} \frac{q_x^2}{\omega^2}$.

Fig.1 shows the intrasubband plasmon spectrum in a weakly disordered array of QW in the case where $M=5$, $d=15a^*$, $a=20a^*$, $p=0$ for two values of the density of electrons of "defect" QW: (a) $N_d/N=0{,}5$, (b) $N_d/N=1{,}5$. The y-axis gives the dimensionless frequency ω/ω_0 ($\omega_0^2=2Ne^2/\varepsilon m^* a^2$ is the plasma frequency), and the x-axis gives the dimensionless wavevector $q_x a^*$ ($a^*=\varepsilon\hbar^2/m^* e^2$ is the effective Bohr radius). As seen from Fig.1, the intrasubband plasmon spectrum in finite array of QW contains M modes. So, the number of modes in the spectrum is equal to the number of QWs in the array. At the same time the propagation of plasmons in weakly disordered array of QW is characterized by the presence of local plasmon mode (LPM). In the case where $N_d<N$, the LPM lies in the lower-frequency region in comparison with the usual plasmon modes (fig.1a). If $N_d>N$, the LPM lies in the higher-frequency region (fig.1b).

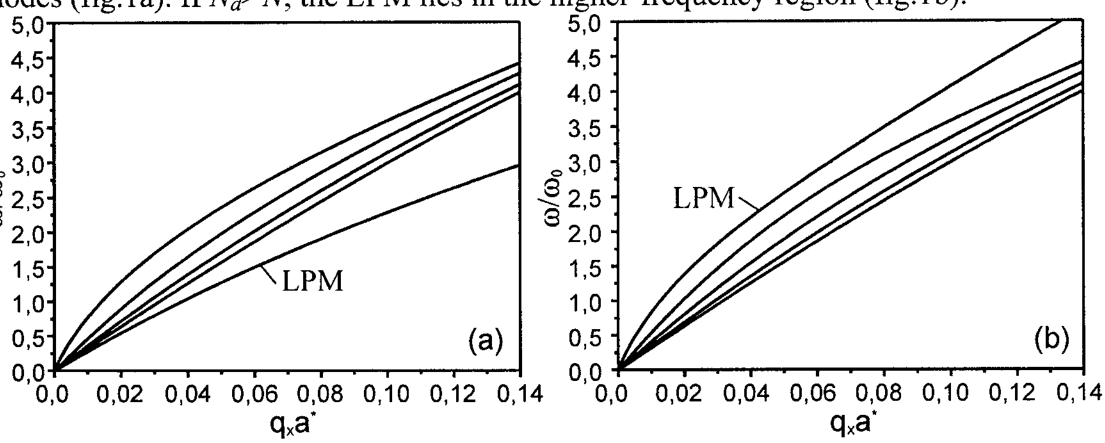

Fig.1

Now we consider the dependence of plasmon spectrum upon the value of 1D electron density in "defect" QW. Fig.2 presents the dependence of plasmon dimensionless frequency ω/ω_0 upon the ratio N_d/N in the case where $q_x a^*=0{,}04$ and for three cases of the "defect" QW position in the array: (a) $p=0$, (b) $p=1$, (c) $p=2$. As seen from Fig.2, the frequency of LPM increases when the value of ratio N_d/N is increased. Also from the

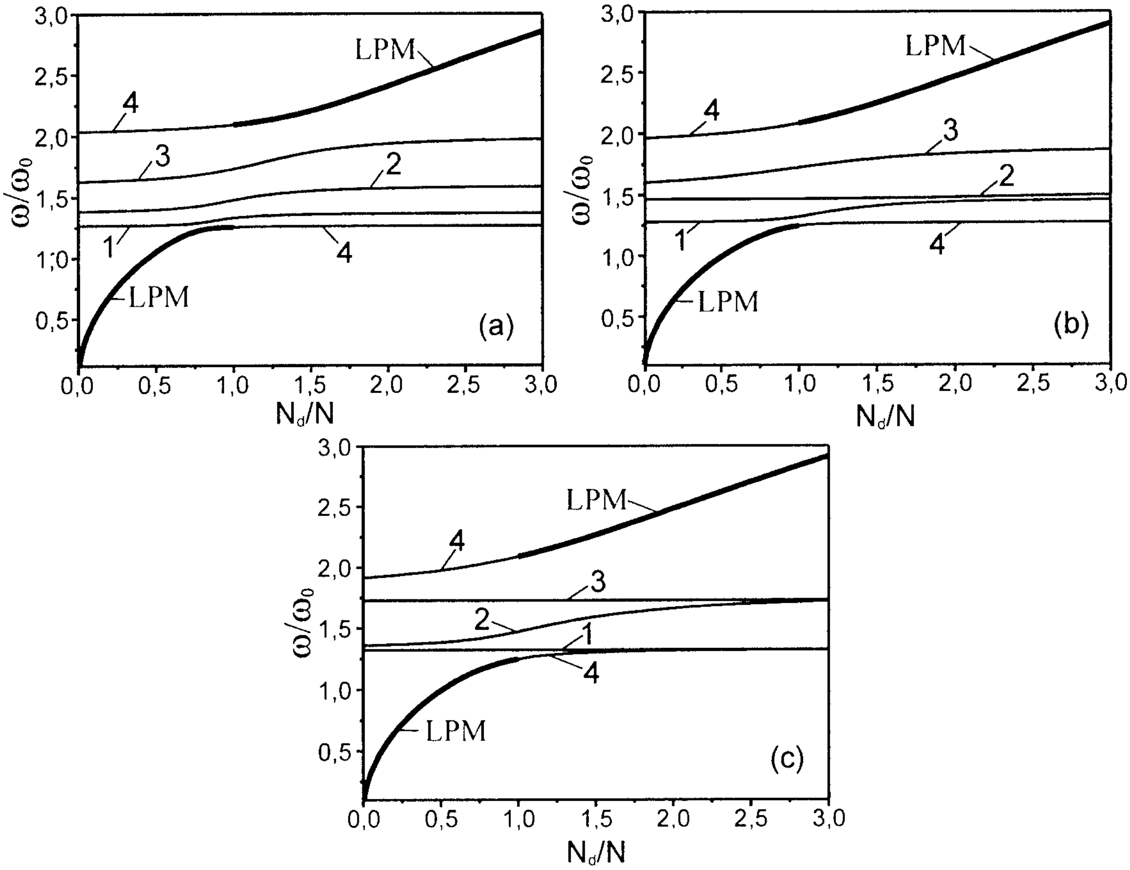

Fig.2

comparison of Fig.2a,b,c it follows that the LPM spectrum depends weakly upon the position of 'the 'defect" QW in array. However, the spectrum of usual plasmon modes is more sensitive to the position of "defect" QW in the array. At the same time, the usual plasmon mode spectrum is characterized by such a feature. As $p=0$ (Fig.2a) when the value of ratio N_d/N is increased, the frequency of all usual plasmon modes also increases. However if $p=1$ (Fig.2b) the frequency of one of the usual plasmon modes (curve 2) does not practically depend upon the value of the ratio N_d/N. In the case where $p=2$ (Fig.2c), there are already two plasmon modes (curves 1 and 3) which possess such a particularity.

CONCLUSION

In conclusion, we calculated the plasmon spectrum of finite weakly disordered array of QWs, which contains one "defect" QW. It should be emphasized that the above-mentioned features of plasmon spectra can be used for diagnostics of defects in QW structures.

REFERENCES

[1] S. Das Sarma and Wu-yan Lai, Phys. Rev., **B32**, 1401 (1985)

[2] S. Das Sarma and E. H. Hwang, Phys. Rev., **B54**, 1936 (1996)

[3] N. N. Beletskii and Y.V. Bludov, Radiofizika i Elektronika, IRE NASU Press, **4**, 93 (1999) (in Russian)